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Journal of the
IRRIGATION AND DRAINAGE DIVISION
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# A METHOD OF FINANCING GROUND WATER REPLENISHMENT

Howard W. Crooke[1]
(Proc. Paper 1860)

## SYNOPSIS

A program of financing ground water replenishment by a dual tax[2] structure in which a replenishment assessment or charge for each acre foot of water extracted from the ground water basin provides the major source of revenue. This program has provided the necessary funds to import sufficient water to stop the continued depletion of the underground water basin in Orange County, California, and to start replenishment of the historical accumulated overdraft. The legal and practical procedures used to institute and administer the program are outlined in this paper.

## INTRODUCTION

Water levels rose an average of five and one-half feet in the underground basin beneath the Orange County Water District last year, November 1, 1956 to November 1, 1957. This was a year in which the local rainfall was only two-thirds of normal—a year in which the inflow into Orange County from the largest watershed in Southern California via the Santa Ana River was the lowest of record—a year in which the total extractions from the ground water supplies of the District were the largest of record. This rise of five and one-half feet in the face of these adverse conditions was the result of the importation of 148,000 acre feet of water transported some 275 miles from the Colorado River into the area of the Orange County Water District for direct use and for ground water replenishment. Present indications are that during the current year, November 1, 1957 to November 1, 1958, there will be another substantial rise in average water level resulting from the continued

Note: Discussion open until May 1, 1959. To extend the closing date one month, a written request must be filed with the Executive Secretary, ASCE. Paper 1860 is part of the copyrighted Journal of the Irrigation and Drainage Division, Proceedings of the American Society of Civil Engineers, Vol. 84, No. IR 4, December, 1958.

1. Secy. Mgr., Orange County Water Dist., Santa Ana, Calif.
2. The replenishment assessment is better defined as a charge than as a tax.

importation of Colorado River water. The program is unique in that the major portion of the funds used for purchasing supplemental water for ground water replenishment is derived from a replenishment assessment or charge levied on the production of ground water.

## The Need for Supplemental Water

Early in 1920's, soon after the City of Los Angeles had completed its Owens Valley Aqueduct, Los Angeles and other cities within Los Angeles County, together with some of the cities in Orange County, recognized the need for additional supplemental water to sustain the foreseeable economic development of the greater Metropolitan Area of which they all are a part. As a result, The Metropolitan Water District of Southern California was created. Bonds were voted equal to approximately ten per cent of the then assessed valuations of the service area of the Metropolitan Water District to build an aqueduct system, complete with the necessary pumping facilities, to move water from the Colorado River and prepare it for use. The result was the Colorado River Aqueduct which the American Society of Civil Engineers has selected as one of the Seven Civil Engineering Wonders of the United States. Three of the original thirteen member cities are located in Orange County, and subsequently, much more of the area of Orange County has been annexed to the Metropolitan Water District. At the present time, the portion of the County which is a part of the Metropolitan Water District contains in excess of 99 per cent of the County's total assessed valuation.

After World War II, people, industry and commerce began moving to the Orange County area in great numbers, causing a critical need for supplementary water. The Orange County Water District started purchasing Colorado River water for ground water replenishment from the Metropolitan Water District in August 1949 with funds derived from an ad valorem tax. The Orange County Flood Control District also bought limited amounts of Colorado River water for ground water replenishment. The finances then available were not sufficient, however, to purchase supplemental water in sufficient volumes to offset the annual overdrafts which were accruing in the District Basin so that the need for finding ways and means of raising money on an equitable basis to pay for more imported water became very urgent.

## Enabling Legislation

A more adequate ground water recharge program was formulated and presented to the California State Legislature in 1953, and legislation was enacted into law effective September 9, 1953 by amending the Orange County Water District Act of 1933. The program thereby provided was designed to achieve the following results:

1. Adequate supplies of ground water for all inhabitants and land owners of the District.

2. Adequate water supplies not only for the present inhabitants and land owners, but also for those yet to come.

3. Realistic financing shared on a proportional basis by those receiving either direct or indirect benefits.

The Orange County Water District encompasses an area of approximately 180,000 acres, with a current assessed valuation of $618,000,000. The area is composed of land which overlies or receives its water from the underlying coastal ground water basin. On November 1, 1956, the average elevation of ground water in this basin was 21 feet below sea level, with wells in some areas producing water from 80 feet below sea level. Engineering studies indicate that sea water has intruded some four miles into the Basin on a three to four-mile front. The average annual overdraft on the natural supply to the District Basin for the past ten years has been determined to be 70,000 acre feet. One of the principal purposes of the replenishment program is to provide the necessary funds to purchase enough water for ground water recharge to replace the annual overdrafts and within ten to twenty years to bring water levels in wells high enough to stop further intrusion of sea water.

Funds of the District are derived from two main sources:

1. A general assessment which cannot exceed 8¢ per $100 of assessed valuation on all assessable property within the District, excluding personal property; and

2. A replenishment assessment or charge on the production of ground water.

The rate for each of these assessments is set annually by the Board of Directors of the District. The general assessment rate now in effect is the allowable 8¢ per $100 of assessed valuation, which will provide approximately $480,000 this year. The current replenishment assessment rate is $3.90 per acre foot of ground water production. Approximately $680,000 in replenishment assessment moneys were collected on water produced during the last fiscal year. The funds derived from the replenishment assessments must be used exclusively for the purchase of water originating outside the watershed of the Santa Ana River to replenish the ground water supply. The funds accruing from the general assessment provide for all other expenses of the District, including capital costs and limited purchases of water as provided in the Legislative amendments.

The first replenishment assessment was levied on June 9, 1954 at the rate of $3.50 per acre foot of water produced, and applied to all ground water produced within the exterior boundaries of the District during the fiscal year July 1, 1954 to June 30, 1955.

In order to determine the validity of the legislative enactment under which the replenishment assessment was levied, and also to determine if the proceedings of the Board of Directors prior to and in the actual levy of the replenishment assessment were in proper order, the District filed an action in the Superior Court of Orange County to determine the validity of the pertinent amendments which are a part of Chapter 770 of the Statutes of 1953, California. Two groups of respondents contested. The case came to trial on November 1, 1954, and a Memorandum Opinion was issued on March 17, 1955 in which the Court found that the replenishment assessment heretofore levied by the Board of Directors of the Orange County Water District was valid. The judgment in the case was appealed by the respondents to the Court of Appeals. On January 17, 1956 the Opinion of the Appellate Court was filed, finding in behalf of the District on all points. A portion of the closing paragraph of the Opinion reads as follows:

"While the situation here is somewhat new, insofar as legal precedents are concerned, it is one presenting problems which are presently of great importance to the district in question, and which in all probability will increasingly continue to present such problems. Under the circumstances, such a charge or assessment should not be held unconstitutional and void where it cannot be held to be in clear and substantial conflict with the fundamental law."

The Supreme Court of California denied a petition for rehearing the case.

## Administration of the New Law

The Legislative provisions and the procedures followed in administering the program are as follows:

1. Legal provision

"Sec. 24. On or before the fifteenth day of January, 1954 all water producing facilities located within the boundaries of the Orange County Water District shall be registered with said district by the operator thereof. Any new water producing facility constructed or re-established after such date shall be registered with said district within 30 days after the completion or re-establishment thereof.

"Failure to register any water producing facility with said district is a misdemeanor punishable by a fine of not to exceed five hundred dollars ($500) or imprisonment in the county jail for not to exceed six months or both such fine and imprisonment."

Procedure followed

A. A "Registration Form" was developed to be used for the registration of each water producing facility in the District. It was designed to secure the information required by the Act, as well as supplemental information deemed necessary by the Board of Directors. It is a simple one-page form, executed in duplicate to provide a copy for the registrant as well as for the District.

B. A complete set of County Assessor's maps for the entire area of the District was procured. These maps show all parcels of land located within the District, and the location of each registered water well has been indicated on these maps.

C. A numbering system was developed whereby a number has been assigned to each registered well which identifies it permanently. This numbering system is correlated with the numbering system used by the County Assessor to identify the particular parcel of land on which the well is located.

D. An informational pamphlet was assembled and distributed to all water well owners and operators. It outlines and explains the procedure necessary to get the replenishment program under way.

E. Necessary personnel was employed and trained to locate all water wells within the boundaries of the District and to assist the operators in completing the registration forms.

2. Legal provision

"Sec. 29. Each operator of a water producing facility within said district shall file with said district on or before February 15, 1954, an information water production statement. Such statement shall provide, among other information which said district may require, an estimate of the total production of water from each water producing facility for the preceding water year, an estimate of the production of water from each water producing facility for the current water year, an estimate of the production of water from each water producing facility for the ensuing water year and information as to the method or basis of making such estimate."

Procedure followed

A. An "Informational Water Production Statement" form was drawn up and mailed in duplicate to all operators of registered water producing facilities, requesting the completion and return of one copy.

B. The information received from the completed forms was tabulated to determine estimated production of ground water for each of the specified years. The information obtained by this means was very helpful in determining potential ground water production for consideration by the Board of Directors of the District at the time of the levy of the first replenishment assessment.

3. Legal provision

"Sec. 25. The district shall annually order an investigation and report to be made by an engineer or engineers employed by said district for the purpose of investigating and reporting upon ground water conditions of said district. The investigation and report shall include among other information which said district may desire, information for the consideration of the board in its determination of the annual overdraft, information for the consideration of the board in its determination of the accumulated overdraft as of the last day of the preceding water year, a report as to the total production of water from the ground water supplies of said district for the preceding water year, an estimate of the annual overdraft for the current water year and for the ensuing water year, and a recommendation as to the quantity of water to be purchased for replenishment of the ground water supplies of said district for the ensuing year."

Procedure followed

The Consulting Engineer of the District was authorized and instructed to make the necessary investigation and report.

4. Legal provision

"Sec. 26. On the second Wednesday in March of each year, the engineering investigation and report shall be delivered to the secretary of said district in writing. Said secretary shall publish a notice of the receipt of such report in a newspaper of general circulation, printed and published within said district, at least 10 days prior to the date at which the public hearing regarding ground water conditions shall be held. Said notice, among other information which the district may provide therein, shall contain an

invitation to all operators of water producing facilities within said district to call at the offices of said district to examine said engineering investigation and report."

Procedure followed

The Engineer's Report on Ground Water Conditions, including a ground water contour map for the area of the District, was submitted as required and the notice of the public hearing was published.

5. Legal provision

"Sec. 26. . . . There shall be held, by the board of directors, on the second Wednesday of April of each year, at the district offices a public hearing at which time any operator of a water producing facility within said district or any person interested in the condition of the ground water supplies of said district may in person or by representative appear and submit evidence concerning the ground water conditions of said district. Appearances, also, may be made supporting or protesting said written engineering investigation and report."

Procedure followed

The public hearing was held as required, and a transcript of the hearing is available to any person concerned.

6. Legal provision

"Sec. 27. . . . On the second Wednesday in June of each year, at the hour of 2 p.m. at the offices of said district, the board of directors shall hold a public hearing for the purpose of determining the need and desirability of levying a replenishment assessment and fixing the rate thereof. In computing and fixing the replenishment assessment rate, there shall be allowed 10 percent for delinquencies. Notice of such hearing shall be given by publication in a newspaper of general circulation printed and published within said district, at least 10 days prior to the date set for said hearing."

Procedure followed

A notice of the required public hearing was published in a newspaper of general circulation and the public hearing was held. A transcript of this hearing is available to any person concerned.

7. Legal provision

"Sec. 26. . . . Said board of directors shall, before the levy of the replenishment assessments, find and determine the average annual overdraft for the immediate past 10 water years; the estimated annual overdraft for the current water year; the estimated annual overdraft for the ensuing water year; the accumulated overdraft as of the last day of the preceding water year; the estimated accumulated overdraft as of the last day of the current water year; the amount of water which should be purchased for the replenishment of the ground water supplies of said district for the ensuing water year, and the sum of money necessary therefor.

"Such finding and determination by said board shall be conclusive and binding upon all persons and parties."

Procedure followed

The Board of Directors made all findings and determinations required in the above cited Section. These were made following the public hearing held on the second Wednesday in June.

8. Legal provision

"Sec. 27. If the board of directors finds and determines that an overdraft, either annual or accumulated, does exist, then said board may levy and assess a charge or replenishment assessment against all persons operating water producing facilities and producing water during the ensuing water year, which assessment or charge shall be computed and fixed at a uniform rate per acre-foot of such water production.

"The total of the replenishment assessment levied in any year shall not exceed an amount of money found to be necessary to purchase sufficient water to replenish the average annual overdraft for the immediate past 10 water years plus an additional amount of water sufficient to eliminate over a period of not less than 10 years nor more than 20 years, the accumulated overdraft; provided, further, that the replenishment assessment in any year as computed and fixed at a uniform rate per acre-foot of water produced shall not exceed five dollars and fifty cents ($5.50) per acre-foot of water produced except upon the vote of eight directors of said district."

Procedure followed

On June 9, 1954, following the public hearing on the same date, after making its findings and determinations as provided in Section 26 of the Act the Board of Directors of the District levied the first replenishment assessment. It was levied at the uniform rate of $3.50 per acre foot of water produced, and was assessed against all persons operating water producing facilities and producing water from the ground water supplies of the District during the ensuing water year, July 1, 1954 to and including June 30, 1955.

In levying the replenishment assessment, the Board found it necessary to determine the probable extractions during the ensuing year in order to arrive at the uniform rate. The method used in determining the rate is illustrated as follows: Suppose, for example, the Board finds and determines that 67,800 acre feet of water must be purchased during the ensuing year and that the water will cost $10.00 per acre foot, then $678,000 will be needed. If the Board determines that probable extractions will be 215,000 acre feet, then the rate is determined by dividing the $678,000 by 215,000 acre feet, which gives a rate of $3.15. The Act requires that there be a 10 per cent delinquency allowance, and therefore the actual replenishment assessment rate would be set at $3.50 per acre foot.

Notices of the Levy of the replenishment assessment and of the uniform rate were mailed to all operators of registered wells.

9. Legal provision

"Sec. 29. . . . The board of directors may, at the time of fixing the replenishment assessment rate, provide by resolution that the operator of any water producing facilities having a discharge opening not greater than two inches in diameter and which do not provide domestic or irrigation

water for an area in excess of one acre may pay a fixed amount as their replenishment assessment, in lieu of filing a sworn statement as to the production of ground water."

Procedure followed

The Board of Directors of the District, in the adoption of the resolution in which they levied the first replenishment assessment, further provided that the operator of any water producing facility having a discharge opening not greater than two inches in diameter and which does not provide domestic or irrigation water for an area in excess of one acre, could pay a fixed amount as his replenishment assessment in lieu of filing a sworn statement as to the production of ground water during the water year. The rate established was $3.50 for each qualifying facility.

10. Legal provision

"Sec. 29. . . . Each operator of a water producing facility within said district shall file with said district on or before the thirty-first day of January, 1955, and on or before the thirty-first day of July, 1955, and thereafter on a semiannual basis on or before the last day in January and July of each year, a sworn statement setting forth the total production in acre-feet of water for the preceding six months period (excluding the month in which the statement is due), a general description or number locating each water producing facility and the method or basis of the computation of such water production. The replenishment assessment is payable to said district on or before the last date which the water production statements shall be filed and is computed by multiplying the production in acre-feet of water as disclosed in the statement, by the replenishment assessment rate."

Procedure followed

"Water Production Statement" forms were prepared in duplicate and mailed to the operators of all registered water producing facilities immediately prior to January 1, 1955. An explanatory letter was enclosed which also offered the services of members of the District staff to aid in the completion of the forms if operators would come to the offices of the District. The water meter requirement (Section 35 of the Act) was not yet in effect when the replenishment assessment was first levied. There were less than 250 water wells which were equipped with water meters. In order to assist operators in assembling proper data for the completion of their water production statements, the District also furnished them with detailed information regarding the correlation between energy used and the amount of water produced, irrigation requirements for many of the crops produced in the area, water usage of the average home, and methods by which to determine the rate of flow from a well. The staff of the Orange County office of the Agricultural Extension Service of the University of California also assisted farmers in their determinations of water produced.

11. Legal provision

"Sec. 35. It shall be unlawful to produce water from any water producing facility within the boundaries of the Orange County Water District from

and after March 31, 1956, unless such water producing facility has been registered with said district and has a water measuring device affixed thereto capable of registering the accumulated amount of water produced therefrom.

"The board of directors by resolution may extend the date from March 31, 1956, on a year to year basis upon its determination that availability, price of water measuring devices, or other circumstances justify such extension; provided further, however, that no extension may be made beyond March 31, 1960. Should said date be extended, notice thereof shall be given by publication in a newspaper of general circulation within said district once a week for two successive weeks to be completed not less than two months prior to said date.

"This section is not applicable to operators of water producing facilities having a discharge opening two inches or less in diameter and which do not provide domestic or irrigation water for an area in excess of one acre who pay, in accordance with district regulations a fixed charge in lieu of affixing a water measuring device.

"Violation of this provision shall be punishable by a fine not to exceed five hundred dollars ($500) or imprisonment in the county jail for not to exceed six (6) months or by both such fine and imprisonment. Each day of operation in violation hereof shall constitute a separate offense."

Procedure followed

The formulation of the 1953 amendments was undertaken in 1952 at the time of the Korean police action, and it was recognized that metals might be needed for defense purposes for an indefinite period of time. It was therefore considered advisable to include in the Act provisions for allowing the District Board to grant an extension of time for the installation of water meters. By the spring of 1957 water meters had been installed on practically all the wells where required.

As soon as it was determined that a substantial number of water meters had been installed, the District employed a meter reader who devotes full time to reading the water meters and the energy meters on all wells and recording the readings on an individual record sheet for each well. The fact that water meter readings are made at random intervals by the Orange County Water District does not relieve the well owner of his obligation to read his own water meters at the start and end of each replenishment assessment payment period.

A sufficient number of readings have been recorded for each well to provide a ready check for the staff of the District to determine any major discrepancies in the water production statements as filed by the operators. By this procedure well owners can be notified when it is determined that their water meters are not recording correctly the amount of water produced. It also provides a method whereby the District staff can be of assistance in determining the probable amount of water production in such situations.

For each of the three water years immediately following the water year 1954-1955, the Board of Directors of the District levied a replenishment assessment on the production of ground water. The rate for the fiscal year 1955-1956 was levied at $3.50 per acre foot. For each of the fiscal years

1956-1957 and 1957-1958 the rate was levied at $3.90 per acre foot. A review of the records of the District discloses that as of April 9, 1958 a total of $2,172,000 has accrued to the replenishment fund as shown in Table 1.

TABLE 1

Record of Water Production and Replenishment Assessment and Charges
April 9, 1958

| PERIOD | PRODUCTION IN ACRE FEET | RATE | AMOUNT COLLECTED |
|---|---|---|---|
| 7/1/54 to 12/31/54 | 80,312.53 | $3.50 | $ 281,093.86 |
| 1/1/55 to 6/30/55 | 66,916.80 | " | 234,208.80 |
| 7/1/55 to 12/31/55 | 84,872.53 | " | 297,053.85 |
| 1/1/56 to 6/30/56 | 66,023.10 | " | 231,080.85 |
| 7/1/56 to 12/31/56 | 105,432.0 | $3.90 | 411,184.80 |
| 1/1/57 to 6/30/57 | 79,158.6 | " | 308,718.54 |
| 7/1/57 to 12/31/57 | 96,640.6 | " | 376,898.34 |
| Total replenishment assessments | | | $2,140,239.19 |
| Penalty and Interest charges | | | 23,029.18 |
| Interest 91-Day Treasury Bills | | | 6,829.00 |
| GRAND TOTAL | | | $2,170,097.22 |

## Engineering Studies

After receiving the Engineer's first "Report on Ground Water Conditions, Orange County Water District," it was determined by the Board of Directors of the District that data pertaining to ground water conditions for preceding years would be very beneficial to the District. Available information was assembled on rainfall both in Orange County and throughout the watershed of the Santa Ana River, measurements of water levels in wells located within the District, and total volumes of Colorado River water delivered to the various agencies which received their basic ground water supplies from the coastal basin underlying the area of the District.

By using the data on water levels in wells, ground water contour maps were prepared as of November first of each year for the period 1930 to 1953. These ground water contour maps were prepared by first locating on a base map of Orange County all wells with water level records available to the District. Beginning in 1928, the Orange County Flood Control District has collected measurements of rainfall, stream flow and water level in wells in Orange County. Measurements of water level have been made in some 1,400 different wells throughout the County, but the number measured regularly at any one time has been about one-third this number. Of the wells measured

regularly, some were measured monthly, some weekly and some continuously with automatic water-stage recorders. The weekly and monthly measurements were made at times to represent, as nearly as possible, the static water-level in the wells unaffected by previous pumping of the well measured or by pumping of adjacent wells.

For any particular year, the elevation of the water level in each well for which the November first measurement was available was marked on the map. In 1957, for example, readings were available for 350 wells. Readings from 66 of these wells were discarded because of the adverse effect of pumping or other factors. The readings for the remaining 284 wells were then used to prepare a ground water contour map for November 1, 1957. These contour lines reflect as nearly as possible the static elevations of ground water in wells, and therefore, the elevation of ground water in the basin beneath the District.

The contour maps are marked off in a grid system with the grid lines spaced at 5,000 feet and being roughly parallel and perpendicular to the Orange County shore line. The elevation at each of these evenly spaced grid points (288 points on the 1957 map) was then used to determine the average elevation of ground water in the District basin.

The 5.5 foot rise in water level from November 1, 1956 to November 1, 1957 is, as stated, only an average rise. In general, the maximum rise occurred in the northern portion of the basin near the spreading grounds and a small rise occurred in the portion of the basin near the ocean. Water levels in some wells dropped a few feet.

These maps, together with the records of natural flows of the Santa Ana River into Orange County shown on Table 2 and the records of Colorado River water purchases, also shown on Table 2, have been used in developing a better understanding of the changes in water storage in the District that have occurred under varying conditions.

Information pertaining to ground water production prior to the installation of water meters is not too reliable since much of it was estimated or computed by using the most reasonable methods then available. Now that water meters have been installed and are being checked periodically, more accurate production data will be available which will provide the basis for further engineering studies. For example, production from each square mile or other unit area within the District could be accurately determined and used in the study of underground movement of water.

## Water Importations

Many of the cities and county water works districts in Orange County have been buying softened Colorado River water from the Metropolitan Water District for several years, and their purchases have been increasing in volume since 1942-1943. Irrigation companies and other agriculturists made their first purchases of unsoftened Colorado River water from the Metropolitan Water District during 1956-1957. It is indicated that the purchases for agricultural use may also be on an increasing basis in future years. These purchases of Colorado River water for direct use have been made for two purposes: (1) To provide a softened water which when blended with the locally produced harder ground water produces water of a quality more desirable for use in the home; and (2) To relieve the draft on ground water supplies.

TABLE 2

WATER SUPPLY CONDITIONS IN ORANGE COUNTY WATER DISTRICT

| Season Oct. 1 to Sept. 30 | Colorado River Water Received from Facilities of MWD for Use in Areas Receiving Basic Groundwater Supply from OCWD Basin | | | Santa Ana River Natural Inflow to Orange County at Prado Dam | Rainfall Index for Orange County | Average Elevation of Water Level in Wells in OCWD Basin |
|---|---|---|---|---|---|---|
| | Softened and Unsoftened Water Purchased for Direct Use | Unsoftened Water Purchased for Groundwater Replenishment | Total MWD Water Purchased | | | |
| | Acre Feet | Acre Feet | Acre Feet | Acre Feet | % of Average | Feet of Elevation above or below sea level |
| 1940-41 | 1,456 | | 1,456 | 174,400 | 238.85 | + 21.3 |
| 1941-42 | 772 | | 772 | 77,920 | 98.70 | + 19.6 |
| 1942-43 | 735 | | 735 | 144,700 | 128.33 | + 20.7 |
| 1943-44 | 4,264 | | 4,264 | 109,700 | 121.36 | + 23.6 |
| 1944-45 | 9,172 | | 9,172 | 102,200 | 109.23 | + 21.7 |
| 1945-46 | 10,908 | | 10,908 | 86,900 | 77.85 | + 17.4 |
| 1946-47 | 10,982 | | 10,982 | 84,200 | 83.84 | + 10.2 |
| 1947-48 | 12,274 | | 12,274 | 59,110 | 52.79 | + 3.8 |
| 1948-49 | 12,902 | 4,669 | 17,571 | 54,537 | 60.43 | - 5.9 |
| 1949-50 | 13,190 | 25,267 | 38,457 | 50,871 | 73.72 | - 10.3 |
| 1950-51 | 14,980 | 28,468 | 43,448 | 44,037 | 59.57 | - 17.2 |
| 1951-52 | 17,591 | 38,157 | 55,748 | 87,074 | 173.18 | - 10.2 |
| 1952-53 | 18,572 | 28,891 | 47,463 | 47,428 | 71.64 | - 17.9 |
| 1953-54 | 21,937 | 61,047 | 82,984 | 53,582 | 89.04 | - 16.1 |
| 1954-55 | 26,504 | 52,442 | 78,946 | 46,689 | 77.01 | - 17.2 |
| 1955-56 | 23,009 | 21,702 | 44,711 | 52,518 | 97.19 | - 21.0 |
| 1956-57 | 45,893 | 102,426 | 148,319 | 43,452 | 66.15 | - 15.5 |
| TOTAL | 245,141 | 363,069 | 608,210 | 1,319,318 | 1,678.88 | |
| AVERAGE | | | | 77,607 | 98.76 | |

The largest volume of Colorado River water ever delivered by the Metropolitan Water District to any agency in any one month was to the Orange County Water District for ground water replenishment, and was in the amount of 21,150.5 acre feet. It was received in June 1957 at a cost of $211,505.00. This large volume, to some extent, constituted a thirty-day test run to determine the adequacy of the spreading works owned and operated by the District in the channel of the Santa Ana River.

## Spreading Operations

The Orange County Water District owns approximately 800 acres of land which is either currently being used or is being developed for water spreading purposes. Additional areas are also available under existing agreements with other agencies. Of the total acreage owned by the District, 725 acres are located in a seven-mile reach of the Santa Ana River channel which overlies the recharge portion of the District Basin. This portion is being maintained in such a manner as to obtain the greatest amount of percolation economically possible from both the natural flows of water coming from upstream and the Colorado River water which is discharged into the river when conditions warrant it.

Two different systems of spreading have been used in handling the imported water received in the river. One system is a series of spreading ponds of ten to fifteen acres each covering the major portion of the river channel and all connected by a by-pass channel. As the water flows down the by-pass channel enough water is allowed to flow into each pond to maintain the highest possible water level and give the greatest amount of wetted surface. Rates of percolation become reduced as silt settles from the water and seals off the surface of the ponds. This system has been used quite extensively and gives reasonably good results, but does require considerable maintenance. The other system is a series of temporary levees parallel with the main side levees and spaced at predetermined distances apart in order that both a minimum of side levee scouring and minimum amount of meandering will occur when water is released at given rates of flow. This second method of spreading when combined with a series of ponds at the downstream end of the spreading works allows for high rates of spreading with a minimum amount of maintenance. This system takes advantage of the gradient in the river which is steep enough to keep the velocities at such rates that silt deposits from the natural flows will be picked up and deposited at the lower end of the spreading works. There it can be mechanically removed from the river or flushed to the ocean during periods of large flood flows.

The spreading of controlled flows works best in years when Nature is stingy with rainfall. The District must at all times preserve the channel of the river as the main trunk flood control channel of the watershed. In years when the storms within the watershed are of high intensity or long duration, the spreading dykes and levees are washed out by the high volumes and velocities of flow. This has occurred on two occasions within the past seven years and in both instances the dykes and levees have gone out as planned. District records also indicate that generally speaking the years in which the spreading works are lost are the years in which the larger natural recharges to ground water occur. The value of these larger natural recharges more than offsets the cost of replacement of the spreading works, since the difference between

the natural recharge and the required recharge to sustain well levels must be supplied by imported water at the current cost of $12.00 per acre foot.

The remaining acreage owned by the District is in two parcels located outside the river channel. These are currently being developed for spreading areas which will be connected directly to the facilities of Metropolitan Water District in order that the District can receive a large portion of its imported water during the winter months when the demands for water from the Metropolitan Water District are the lowest. When this system is in operation it will provide an opportunity to let the river area dry out each summer and be in better condition to absorb a larger percentage of the winter and spring runoff. One of these spreading sites is approximately twenty-five acres and is being excavated to a depth of fifteen feet; the other, a sixty-five acre site, is being excavated to a depth of thirty feet. Both areas will be surrounded by dykes five feet high to keep out any local runoff and its accompanying silt and clay load, thereby minimizing the maintenance cost.

## RESULTS

The annual engineering reports on ground water conditions in the Orange County Water District indicate the average water level in wells had lowered from 21.3 feet above sea level in 1940-1941 to 17.2 feet below sea level in 1950-1951. This drop of 38.5 feet in the average water level occurred during a ten-year period in which 148,583 acre feet of Colorado River water were imported to supplement the natural supplies. The reports also indicate an additional drop of the average water level in wells to 21.0 feet below sea level in 1955-1956. This additional lowering of 3.8 feet in the average water level in wells occurred during a five-year period in which 309,852 acre feet of Colorado River water were imported. The Engineer's Report on Ground Water Conditions for the water year 1956-1957 indicates a rise in the average water level in wells of 5.5 feet during the one-year period from November 1, 1956 to November 1, 1957 in which the total importations of Colorado River water were in the amount of 148,319 acre feet as shown on Table 2.

Based on the experience to date, the Board of Directors of the Orange County Water District is proceeding in the belief that a well-balanced adequate supply of ground water for all land owners and inhabitants of the District can be financed by the present dual assessment system, and that the replenishment assessment or charge on the production of ground water is fair, equitable, and practical for the area of the Orange County Water District.

Paper 1861 December, 1958 IR 4

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# STATEWIDE WATER PLANNING[a]

Harvey O. Banks,[1] M. ASCE
(Proc. Paper 1861)

## ABSTRACT

This paper discusses the importance of long-range planning in development of water, with due consideration of the needs of all areas and of all uses and demands. With particular reference to water development in California, the paper discusses the State's three-phase investigation: (1) an inventory of resources; (2) an inventory of requirements; and (3) a master plan for conservation and redistribution of the State's water supplies.

Nowhere in the fields where civil engineers ply their skills and knowledge is the need for long-range planning more necessary than in the development of water resources. This is true especially when the problems are statewide in scope, as in California.

In several of the 48 states long-range plans are being proposed and implemented for the control and conservation of water. Texas (1) has moved forward by enacting a 200 million dollar loan program to assist municipalities and river authorities in building water projects, and the Texas Legislature also appropriated funds to develop a comprehensive state water plan. In New Jersey (2) various interests have gotten together on a water supply plan involving the Raritan and Delaware Rivers. And many are familiar with the long-range planning for water development in the State of California.

## $6 Billion in Water Projects

During the past 75 years Californians have built water and power projects valued, at today's prices, at some $6 billion. Many of the projects were constructed at times when the State's population and financial resources were far

Note: Discussion open until May 1, 1959. To extend the closing date one month, a written request must be filed with the Executive Secretary, ASCE. Paper 1861 is part of the copyrighted Journal of the Irrigation and Drainage Division, Proceedings of the American Society of Civil Engineers, Vol. 84, No. IR 4, December, 1958.

a. Presented at the June, 1958 ASCE Convention in Portland, Ore.

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less than today, and only a fraction of what those resources will be in the future.

These have been noteworthy developments, the majority of them accomplished by local initiative. Out of such a record of achievement, however, two facts stand out. First, very few of the developments have been built according to a coordinated comprehensive plan affecting a major portion of the State. The outstanding exception is the Central Valley Project, conceived by the then State Engineer and his staff and later built by the Federal Government; and it serves only portions of the Sacramento Valley, the Delta and portions of the San Joaquin Valley. Secondly, in spite of the combined efforts of the many agencies planning and building these California water projects up to now, we are fast losing the race to keep apace with the booming growth in population, agriculture and industry.

There is no need in this paper to justify long-range planning. However, certain aspects, as related to water development, deserve repetition and emphasis. It is well recognized that water has become a scarce resource in many areas; in southern California, for instance, local resources have long since been almost fully conserved and put to beneficial use. On the other hand, the damages sustained from uncontrolled floods continues to mount with more intensive and extensive development of the land. The erratic occurrence of natural runoff necessitates increasingly expensive physical works to control and conserve the available water resources. Most of the good, and cheap, dam and reservoir sites have already been utilized. It behooves us to make full use to the extent economically possible, of the remaining sites, which are all too few in number and expensive to develop. Planned utilization of ground water resources and underground storage capacity will become increasingly necessary.

The demands on our water resources are many and diverse, ranging from municipal, agricultural and industrial use, fish and wildlife, and recreation, to the use of streams and ground water basins for waste disposal. Many of these demands are incompatible. Different areas are in competition with one another for available water resources. These conflicts in interests and demands, and the competition for water, both by areas and by type of use, are serious now and must inevitably increase in severity with time. Without continued, comprehensive long-range planning, and development within the framework of such planning, it is highly probable that some areas and some uses will lose out in the race for adequate water supplies. The objective to be sought is balanced development and use for optimum long-range total benefit, with due consideration of the needs of all areas and of all uses and demands. In view of the increasing scarcity of unused water resources, the ever-increasing demand therefor, and the expense involved in providing flood control and adequate water supplies, we must insure that we do not make mistakes now which may be extremely costly to rectify at a later date.

In California, at least, the State itself acting through the Department of Water Resources is the only agency with sufficiently broad authority and scope of interest to do the master planning that must be done.

## History of Long-Range Planning

Looking back over the span of California's history, one can see that long-range planning has been a vital factor in development of the water resources of the State. That history begins within a few years of the Gold Rush when

Californians discovered a fact of nature with which we must live. The State's water resources and requirements are very much out of balance geographically as well as with the growing season.

It was soon found that while the northern streams poured large amounts of water into the ocean, sometimes with violence, the vast valleys in the central and southern sections of the State often were in short supply, and particularly during the late summer and fall when the water was most needed.

Recognition of this imbalance prompted early planning efforts to resolve the State's water problems.

In 1866, less than two decades after gold was discovered, the State Legislature appropriated funds for a study of a water supply canal running south along the west side of the Sacramento Valley. While this was not exactly statewide planning, it was a significant beginning for a youthful and largely undeveloped state with a population of only 380,000.

Twelve years later, in 1878, the Legislature approved "An act to provide a system of irrigation, promote rapid drainage and improve the navigation of the Sacramento and San Joaquin rivers," encompassing the entire area known today as the California Central Valley. William Ham. Hall was selected as the State Engineer to direct the investigation demanded.(3) Hall's planning work was remarkable. First, he was working on an area basis in a region 500 miles long and containing more than ten million acres of irrigable land. Second, his planning was based on almost no factual data as to hydrology, at least according to modern standards. Nonetheless, his work has withstood the test of time, and formed the basis for many later studies and plans for the water development of the Central Valley. Many of his basic concepts are incorporated in today's master planning.

In the rapid development of the Central Valley area in the twenties, water supplies were used without a comprehensive plan for their conservation, presenting many serious water problems. These problems had been aggravated by a period of subnormal precipitation beginning in 1917. As a result, the irrigation draft on underground supplies was unusually heavy, causing alarming drops in ground water levels. Further, salt water from San Francisco Bay was encroaching into the channels of the Sacramento-San Joaquin Delta, causing their waters to become unfit for irrigation.

## Comprehensive Investigation Ordered

Recognizing the seriousness of these conditions, the State Legislature in 1921 directed a comprehensive water resources investigation. In addition to the State Division of Water Resources, many consulting engineers, geologists, economists, agriculturists, attorneys and financiers were employed to assist with the studies. In 1931, the completed State Water Plan was presented to the Legislature.

The initial unit of the plan, the Central Valley Project, was authorized in 1934 by the Legislature as a State enterprise, along with provision for its financing, construction and operation. A bond issue of $170,000,000 its estimated cost, was authorized. Because of economic conditions in 1934, the bonds never were marketed, and the State turned to federal assistance. Today the Central Valley Project is being constructed and operated by the U. S. Bureau of Reclamation. It stands as a great monument to the vision of planners like William Ham. Hall and his successors in California over the span of a half century.

The basic concept of the State Water Plan was the moving of surplus water from the northern reaches of the Central Valley to the water deficient areas in the southern end of the Central Valley, a project to transport water a distance of some 500 miles, covering two-thirds of the State. Therein lay the major limitation of the State Water Plan. Impressive as it was, it was not sufficiently statewide in scope. It did not extend into that vast area south of the Tehachapis, where water deficiencies were even greater, and where problems soon were to be compounded by one of the greatest mass migrations in history.

With the outbreak of World War II, people from all sections of the United States began moving to California, and they have not stopped coming. Equally important, industry and commerce began a strong westward movement which has accelerated with each passing year.

## More Water for More People

In 1940, California's population was 6,907,387. Today it is 14,700,000, based on accepted standards for population estimating. In just 17 years the state population has more than doubled. In some areas of the State, population has doubled in five years. By 1975, reliable forecasts indicate a population of 23 or 24 million.

The effect of such growth on water developments planning cannot be overestimated. Estimates of water requirements are out of date almost before they are surveyed and calculated by the engineers. Entire cities start up where only months before bare fields existed. More and more land goes under cultivation to supply the ravenous demands of these metropolitan centers.

California's planners sensed the trend even during the war years, but with manpower then at a premium, nothing could be done until the end of hostilities. As conditions returned more nearly to normal, the State Legislature in 1947 directed another comprehensive water resources investigation, this time encompassing the entire State, and every possible use of water, and staged for that date in the future when the State will, to all intents and purposes, be under ultimate conditions of development.

The investigations, completed after ten years of study and expenditure of about eight million dollars, have been presented to the State Legislature for acceptance as the broad master plan to guide and coordinate future water developments by all agencies. The need for a master plan to coordinate the activities of the manifold entities engaged in water development, Federal, State, local and private, to a common objective and for maximum overall benefit, cannot be too strongly emphasized. Such a plan is of great assistance in the administration of water rights.

## Water Resources Inventoried

First phase of the investigations was a thorough inventory of all of the State's water resources, which determined that there occurs within the State an average annual total of 71,000,000 acre-feet of runoff. To this must be added our rights to the use of 5,362,000 acre-feet annually from the Colorado River. This inventory also showed, however, that the majority of the supply was available in the northern third of the State. On the other hand more than two-thirds of the present and ultimate requirement is in the central and southern two-thirds of California.(4)

It should be emphasized that the figure of 71,000,000 acre-feet runoff is an average over a 53-year period. Annual seasonal natural runoff for the entire State has varied from a minimum of only 18,300,000 acre-feet in 1923-24 to a maximum of 135,000,000 in 1937-38.

Second phase of the planning was an equally thorough inventory of California's water requirements as of the present and of those which will exist when the State is completely developed, as best as can be foreseen now. This was based on known water use of today, projected cropping patterns, land classifications, and estimates of population and commerce. Through these studies, it was estimated that the total consumptive water requirement including irrecoverable losses, with full development will be about 51,000,000 acre-feet annually, with agriculture requiring about 80 per cent of that amount.(5)

At first glance it would appear that the solution to the problem is comparatively simple, and that there would be a fairly large margin of safety between total supply and ultimate requirement.

Actually, it is very complex because of the intervening mountain ranges between the area of major supplies and areas of major need, the wide range of conditions found in California, from rain forest to arid desert, the necessity for minimum involvement of presently vested water rights, the wide variation in runoff seasonally and from year to year, and because of the vast new area of public policy which must be explored in entering such a tremendous undertaking.

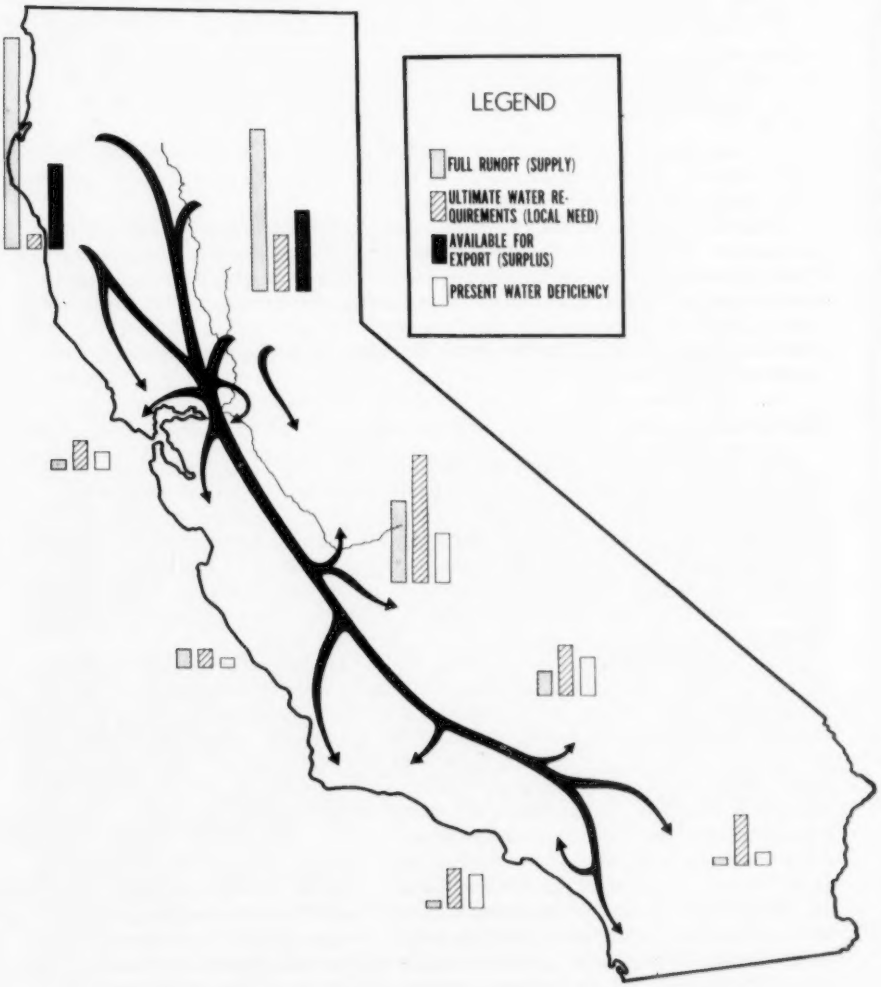
## Master Water Plan

With these factors in mind, the third and final phase of the investigations was undertaken: a master plan for conservation and redistribution of the State's water supplies. The objective of this plan is to show how the imbalances of nature can be corrected and water can be provided for all areas of California for all uses to the extent that and when, it is necessary and practical to do so. Plate No. 1, "Ultimate Development and Transfer of Water Under the California Water Plan", pictures the areas of surplus and areas of water shortage, and the general transfer plan.

The California Water Plan(6) gives full consideration to the use of water for municipal, agricultural, and industrial purposes; to hydroelectric power development; that is, the full development of the hydroelectric power potential consistent with other demands on the water resources concerned and the available storage capacity; to flood control needs; to protection of the quality of fresh water; to waste disposal and drainage, and to the interests of fish, wildlife and recreation. It considers the needs of all areas of the State. Its full implementation would involve the construction of some 376 new major reservoirs throughout the State, with a total storage capacity of about 77,000,000 acre-feet, to be added to the 20,000,000 acre-feet of storage available in existing reservoirs. Conjunctive operation of underground and surface storage will be necessary to achieve the degree of conservation necessary. Heavy emphasis has been placed on enhancement of fish and wildlife resources and on development of the recreational potential because of the social and economic significance to the future well being of Californians.

The California Water Plan demonstrates that it is physically possible to provide foreseeable water needs of a future population in excess of 40 million; for a threefold increase in irrigated agriculture; and for nearly a fivefold growth in the related municipal and industrial economies.

# WATER TRANSFER PLAN



The first unit of The California Water Plan authorized to be built by the State is the Feather River Project. It is the first project of its size to be attempted anywhere in the world.

## Oroville Dam is First Step

The key unit of the project is a dam to be constructed on the Feather River, about five miles above the City of Oroville. The structure will be 730 feet high, which is 20 feet higher than Hoover Dam. Behind the dam will be a reservoir with a storage capacity of 3,500,000 acre-feet of water, and a shoreline of 167 miles.

Water will be released from the reservoir, flow downstream into the Sacramento River, and from there it will travel south into the Sacramento-San Joaquin Delta Region. Facilities will be constructed to permit the water to cross the Delta without becoming contaminated with salt water coming up from the Bay Area.

From the Delta, the water will be carried south by a series of pipelines, aqueducts, tunnels, and pumps for distribution to the deficient areas in many parts of the State all the way to San Diego County.

Other benefits will be realized from the Feather River Project in addition to furnishing water to areas of need and providing flood control for the valley. Hydroelectric power will be developed from generating plants to be constructed in connection with the project. Fishing and other recreational activities will be expanded by various features of the project.

Cost of building the Feather River Project is estimated at $1,600,000,000. It has been found to be economically and financially feasible. First work was started in the spring of 1957 with relocation of roads, railroad tracks, and utilities. Forty per cent of this relocation work, for which financing has been obtained, is now under contract.

While this preliminary work done on the Feather River Project puts the state actively in the construction business, The California Water Plan is not a construction proposal, nor is it a hard and fast listing of individual projects which will be constructed at some future date. It is not a proposal for exclusive state construction; rather we envision a continuing and even closer cooperation and coordination between the federal, state and local governments as well as private interests, to meet our rapidly growing water needs, within the framework provided by The California Water Plan.

The dams, reservoirs, canals, and pumping plants described briefly in the report on The California Water Plan merely represent those works which appear, in light of today's conditions, to be the best means of accomplishing an equitable distribution of the State's remaining available uncommitted water resources to the benefit of all areas and all uses. As conditions change, and as the State grows, acceptable or better alternatives to the listed work may be found. Or, under changing conditions, some of them may never be built. Technological advances, in pen water conversion for instance, may render some of our planning obsolete.

In any case, before a single one of the works is built, or even proposed as a project for construction, there must necessarily be detailed study given to all aspects of the project, including its impact on local areas, water rights, matters of water quality, rights of way, and all other matters affecting its feasibility, including economic and financial analyses.

Planning is Continuous

All of these detailed studies relate to planning, of course. This may lead to the question: When does planning end?

The answer to that question is that planning must be a continuous process. This principle has been well recognized in our work in California. The first unit of The California Water Plan, the Feather River Project, barely is underway. Our Division of Resources Planning, however, already is underway with more detailed planning on the next phases of The California Water Plan. Under the California Water Development Program, the planning engineers are doing more detailed exploration work to determine fitness of dam sites and locations of other works and to investigate the feasibility of specific projects for which a need can be foreseen in the near future.

Whether or not any of these projects now in the second stage of planning will be built, beginning perhaps before the Feather River Project is completed, depends on many factors. These include questions of need, financial conditions, and determination of policy decisions which were discussed earlier. Engineers of the California Department of Water Resources, or any other similar organization, would be derelict in their responsibility if they failed to have plans ready when they were needed and when that need incites authorization by the proper authorities.

In any planning effort, such as The California Water Plan, the engineer only can give an orderly presentation of the future requirements as seen in light of present conditions.

Planning cannot be static. Plans must be brought up to date on a continuing basis to meet the new requirements in light of future conditions and changing technology.

This flexible attitude toward the development of water resources is the concern not only of the engineer, but also of all who share with the engineer the vital functions of planning. The final responsibility, however, falls to the engineer, for this is an engineering problem.

Rome was not built in a day. Great water projects sometime span decades from conception to completion. Planning to meet requirements of future populations must be a continuing process. The needs of the future will provide the challenge on which engineering thrives.

REFERENCES

1. Engineering News-Record, July 11, 1957; 159:p47-8.
2. Journal, American Water Works Association, August 1957; 49:969.
3. Bulletin No. 1, "Water Resources of California", State Water Resources Board.
4. Bulletin No. 1, "Water Resources of California", State Water Resources Board.
5. Bulletin No. 2, "Water Utilization and Requirements of California", State Water Resources Board.
6. Bulletin No. 3, "The California Water Plan", State Water Resources Board.

Paper 1862 December, 1958 IR 4

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# MODEL APPROACH TO A GROUNDWATER PROBLEM

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(Proc. Paper 1862)

## SYNOPSIS

When adverse field conditions preclude a direct field investigation of a groundwater problem, models can often be utilized to advantage to determine directions of flow, velocities, location of hydraulic divides, and to forecast conditions which may occur in the future. Two types of models, electric analog plotter and hydraulic, were found satisfactory for investigation of a groundwater problem located in an unconfined aquifer.

The electric analog plotter was somewhat limited by the necessity of assuming a one-density system, but otherwise it offered good detailed information on the flow patterns. The hydraulic model operated satisfactorily with different density liquids; non-equilibrium conditions were readily studied; and a time scale was introduced making it possible to forecast future events which would be most difficult to obtain by mathematical analysis.

The results of the two models checked each other in their field of mutual results, which shows their usefulness in the investigation of groundwater problems.

## INTRODUCTION

This paper presents a method of approach toward solving groundwater problems when field conditions, because of physical or economic reasons, preclude a more direct field investigation.

This study was initiated to determine whether model studies, both hydraulic and electric analog plotter types, could be set up based on several known field conditions to determine the unknown field conditions. The unknowns include location of hydraulic divides, directions of flow, and projection of events into the future.

Note: Discussion open until May 1, 1959. To extend the closing date one month, a written request must be filed with the Executive Secretary, ASCE. Paper 1862 is part of the copyrighted Journal of the Irrigation and Drainage Division, Proceedings of the American Society of Civil Engineers, Vol. 84, No. IR 4, December, 1958.

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The actual problem to which the model tests were applied was the disposition of papermill wastes, sometimes called "lignin" and more accurately named "lignosulfonate," by ponding on the surface of the ground and allowing subsequent infiltration into the groundwater. The field location of the waste disposal problem is 5 miles south of Wausau, Wisconsin, in the Wisconsin River Valley. The infiltration ponds were located 350 feet from the west bank of the Wisconsin River. Directly across the river, 600 feet from the east bank, was an industrial water well pumping about 500 gpm.

The waste liquid, upon reaching the groundwater, traveled along with the groundwater and discharged into the river. Some waste, however, found its way into the zone of influence of the well and subsequently contaminated the well water.

## Geo-hydraulic Conditions

The Wisconsin River has produced a terrace and flood plain system about a half mile wide at the ponding area. Hills of Precambrian rock to the east and west outline the old river valley. The present river channel is 400 feet wide and is about 60 feet below the highest terrace of the valley and about 30 feet below the ground elevation bordering the river. A crystalline rock basement of Precambrian age, the center of the preglacial valley, is about 125 feet below the ground in the ponding area.

The aquifer is unconfined and composed of sand and gravel. In the lower terrace upon which the ponds are dug it ranges in thickness from 100 feet to 130 feet. The water table in this terrace ranges from about 5 feet below the surface near the ponds to about 25 feet below at the well.

From a pumping test it was determined that the transmissibility coefficient was about 100,000 gpd/ft and the coefficient of storage was about 0.10.

On the west side of the river the movement of groundwater is normal to and toward the river. On the east side of the river the groundwater movement is much more complicated because of the cone of depression of the well interacting with a constantly changing river elevation. It is also affected by a negative boundary condition to the east. The movement of the groundwater on the east side of the river is toward the well in the area of influence of the cone of depression. Outside of this cone the general movement is toward the river. The cone of depression of the well intersects the river at all times except briefly during periods of river stage recession.

The average gradient of the piezometric surface to the west of the river is 0.006 ft per ft. The normal nonpumping gradient on the east side of the river could not be determined because of the nearly continuous pumping of the well. From a detailed study of the negative boundaries and recharge zone, however, it was estimated at 0.003 ft per ft.

## Model Studies

The two models used in this study were the electric plotter shown diagrammatically in Fig. 1, similar to the Analog Field Plotter, and the hydraulic model as shown in Fig. 3.

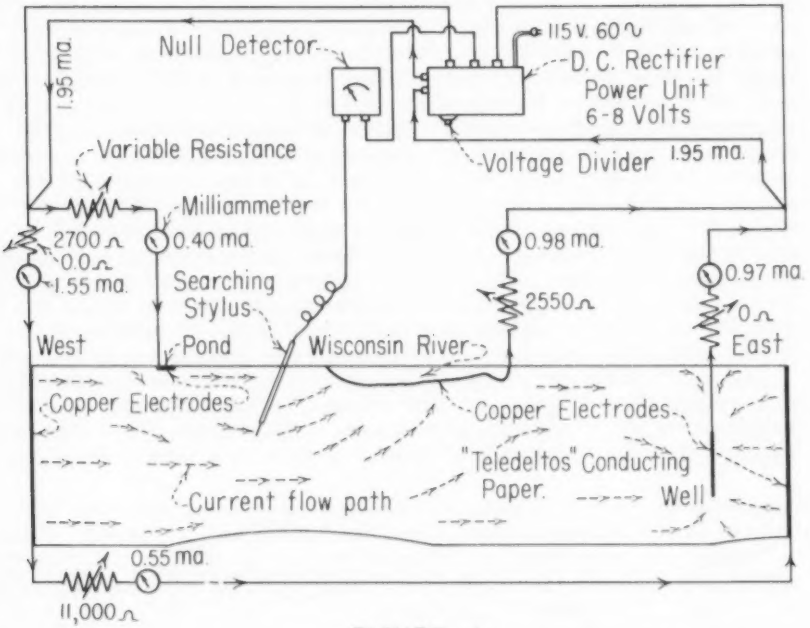


FIGURE 1

# ELECTRIC ANALOG PLOTTER MODEL

## ELECTRIC CIRCUIT

### Electric Plotter

The advantages of the electric plotter are the ease with which it can be set up to fit almost any situation and the speed and accuracy with which the equipotential lines can be plotted. It is limited, however, to two-dimensional operation and cannot be used to investigate the flow patterns of liquids of different densities.

In applying the model to the problem at hand, conducting paper (carbon-impregnated Type L Teledeltos paper) was cut to represent a cross-section of the aquifer normal to the river and passing through the pond and the supply well on either side of the river (see Fig. 1). The representative width was chosen as 60 feet so as to coincide with the scale and dimensions of the hydraulic model.

To obtain a quantitative determination of the current flow within the conducting paper, it was necessary to control the current input at each of the several sources and output at each of the sinks. This was done by using variable resistances and adjusting them until, with the aid of milliammeters, the parallel circuit was balanced as desired—the current in the sources and sinks being proportional to those in the field. The sources were the west groundwater increment, the east groundwater increment, and the pond. The sinks consisted of the river and the water well.

The operation of the electric plotter is based on the fact that Ohm's law

(E = RI) is similar to Darcy's law for two-dimensional laminar flow (H = KQ), where E corresponds to head H, R to hydraulic resistance K, and I corresponds to rate of flow Q. The groundwater sources, represented by the electrodes at either end of the conducting paper, supply about 37,200 gpd from the west and 20,500 gpd from the east in a 60-foot-thick section. So the current supplied to the electrodes was 1.00 milliampere and 0.55 milliampere, respectively. The pond electrode was supplied with 0.40 milliampere representing about 14,900 gpd. Difficulty was encountered in representing the three-dimensional radial flow around the well in a two-dimensional linear-flow model. The approach was to use 5 percent of the total discharge as the representative discharge, so that 0.97 milliampere was taken out at this sink, representing 36,000 gpd. The rest of the current in the circuit had to leave by the river electrode and amounted to 0.98 milliampere, equivalent to 36,600 gpd. The total current put into the circuit amounted to 1.95 milliamperes representing 72,600 gpd; thus 1.00 milliampere was equivalent to 37,200 gpd.

The results of the electric plotter are given in Fig. 2. Note that the path of the waste from the pond to the river shows very little downward movement, traveling only through the very upper portion of the aquifer. This is due to the fact that the waste had to be considered as having the same specific gravity

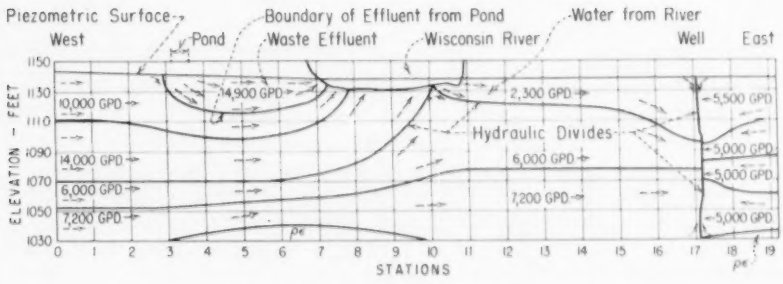


FIGURE 2

ELECTRIC ANALOG PLOTTER MODEL STUDY
CROSS SECTION - CENTRAL PART OF VALLEY

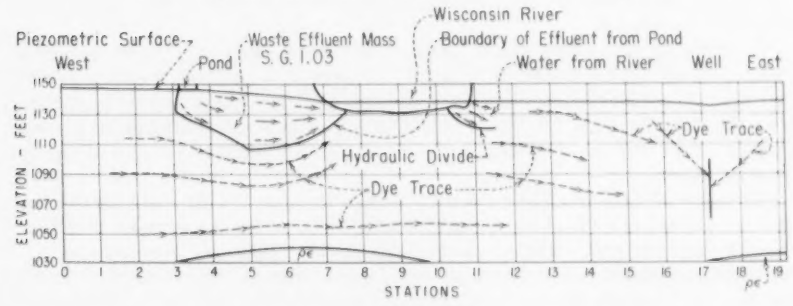


FIGURE 3

HYDRAULIC MODEL STUDY
CROSS SECTION - CENTRAL PART OF VALLEY

as the water and because it was impossible to show the mixing of the two miscible fluids. The groundwater from the west divided at elevation 1070—that above 1070 discharged into the river while that below traveled to the well. The river also contributed water to the well, the boundary of this discharge starting at station 10+11 and leveling out at elevation 1121 in its travel to the east.

## Hydraulic Model

The conditions set up on the electric plotter were also set up on a hydraulic model. The advantages to be gained from this type of model are that fluids of any density can be used, nonequilibrium conditions can be studied, and future events can be forecast. The model as constructed for this study has an infinite variety of applications and is limited in use only by the ingenuity of the investigator. Its purpose was three-fold: first, to check the results of the electric plotter for flow with one liquid of constant density; second, to determine the effect of adding another liquid of greater density to the system; and third, to study nonequilibrium conditions such as those produced by creating a flood stage in the river, stoppage of ponding, or changing the discharge of the well.

The model was constructed to correspond to the proportions of the electric plotter. See Fig. 4. The dimensions chosen were 96 inches by 24 inches by 3 inches. The sides were made of 3/8-inch lucite held together by small structural steel angles. An 80-mesh copper screen was used at either end of the model to obtain a constant vertical potential at those points. The 80-mesh screen was also used to construct the well. A 20-mesh screen was used for the river and pond lining. The Precambrian basement domes were made of

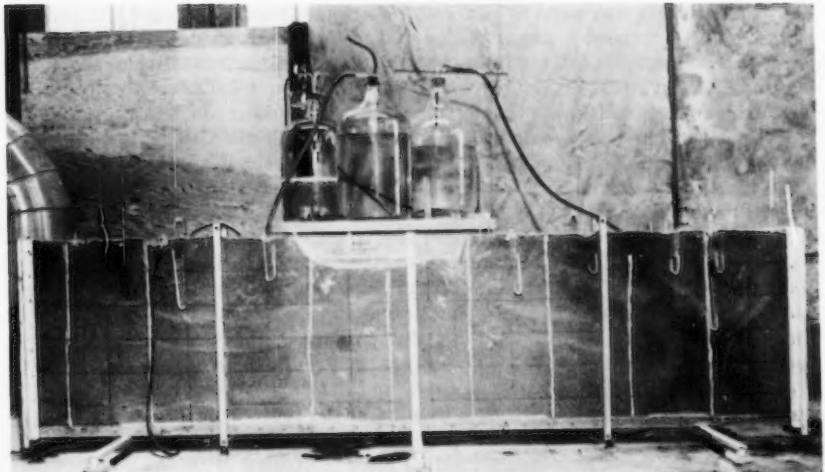

FIG. 4 - HYDRAULIC MODEL

glazing putty, as were the vertical quarter-inch deep strips placed every 10 inches to insure against short-circuiting the liquids along the sand-lucite interface. The aquifer consisted of silica sand from a local gravel pit and had a porosity of 32 percent. The size analysis of the sand was as follows:

| Sieve Size | Percent as Large or Larger |
|---|---|
| 20 | 11.3 |
| 40 | 47.5 |
| 60 | 81.6 |
| 80 | 96.4 |
| 100 | 98.4 |
| 200 | 99.9 |
| Pan | 100.0 |

The path and velocity of the water in the model were determined by use of fluorescein dye injected through glass tubes which had been inserted into the sand aquifer. The tubes had tapered points to control the amount of dye injected and to keep the tube from becoming plugged with sand. The pH of the dye was reduced to 7-1/2 to match the pH of the water. To trace the movement of the waste from the pond, dye was added directly to the pond. The piezometric surface was determined from manometer tubes placed at various points along the length of the model. The liquids were added to the model by use of rubber tube siphons and constant head bottles.

All liquid movements in the model were due to gravity, all movement being laminar flow with Reynold's number controlling the hydraulic similitude obtained.

In applying this model to the Wisconsin River Valley problem, a calcium chloride solution was used to represent the waste fluid. The specific gravity of the solution was made the same as that of the waste fluid—1.03. The quantities introduced into the model were limited by the permeability of the sand aquifer. All quantities were proportional to and about 0.0006 of the field quantities. To simplify the measurements, convenient reductions were made as follows: 37,200 gpd would be represented by 37.2 milliliters per 40 seconds, and 14,900 gpd by 14.9 milliliters per 40 seconds. The dye markers were placed at critical points to locate hydraulic divides and to determine typical velocities.

The results of the hydraulic model test are shown in Fig. 3. The ponded waste interface reached a minimum elevation of 1106 feet, while in the field it could be expected to be much lower than this. The depth to which the waste sank in the aquifer is partially a function of time, and thus the 135-day travel time in the field can be expected to result in deeper penetration than the 2-hour travel time in the model. This discrepancy could be minimized, however, by using smaller model quantities and thus lower velocities. This would, of course, extend the length of time of the test.

The discharge from the river to the well was easily defined because the river water had been heavily colored by the dye coming from the pond. The discharge zone began at station 10+30 and in traveling to the well leveled off at elevation 1121.

The nonequilibrium conditions caused complete reversals of flow in some instances and only minor changes in velocities or direction in others. Effects

of stoppage of ponding or well discharge were simulated simply by cutting off the respective model source or sink. The condition of river flood stage was simulated by adding water directly to the river so that the elevation of the river surface rose to the appropriate level.

Forecasts of future conditions were made by relating model velocities of waste and water movement to the field velocities by using a determined velocity ratio. A velocity ratio of 1 inch per minute in the model equal to 10 feet per day in the field was arrived at by equating model velocities with known field velocities. The field velocities were determined by actual field tests and confirmed by analytical methods.

## Comparison of Results

In order to compare the results of the hydraulic model with those of the electric plotter, ordinary water was used in the hydraulic model to represent the ponded waste. In this way identical conditions were created in both models. The results of the tests of the two models are shown in Fig. 5. The ponded waste boundary in the hydraulic model reached a minimum elevation of 1113 feet, while that in the electric plotter model reached only 1116 feet. The interface between the discharge from the river and from the west groundwater source to the well was somewhat above and to the east of the interface as determined by the electric plotter. The hydraulic divide between the west groundwater going to the river and to the well as determined by the electric plotter model is within a few feet of the divide determined by the hydraulic model. The results of the two types of models are close enough that either model can be considered reliable and capable of producing satisfactory results when movements of liquid of one density are being investigated.

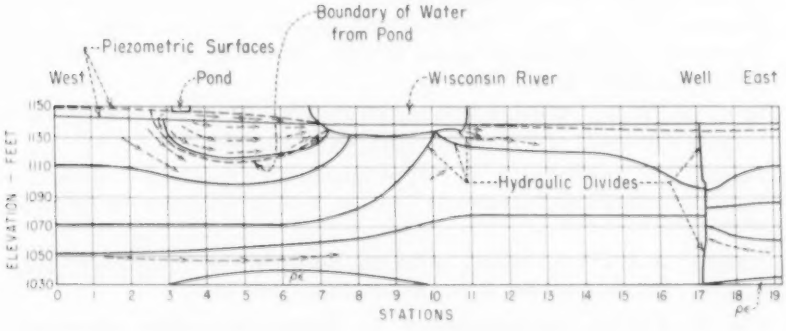


FIGURE 5

COMPARISON OF

HYDRAULIC MODEL

AND ELECTRIC ANALOG PLOTTER MODEL RESULTS

USING ONE DENSITY SYSTEM

HYDRAULIC MODEL - - - - - -

ELECTRIC MODEL ————

The model results check with known field conditions, except that the sinking of the waste in the models is minimized. The contribution of water by the river to the cone of depression of the well has been verified by mathematical analysis and field observations. The movement of water under the river from west to east has also been verified by waste-liquid contamination tests performed in the field. Several fluid velocity measurements made in the field have also checked out the comparable velocities as determined in the model.

## CONCLUSIONS

From the model tests described and the results obtained, it can be stated that quantitative groundwater analyses can be made on either the electric plotter model or the hydraulic model. Directions of flow are easily determined by the path of the dye streaks in the hydraulic model and by the indicated potential drops in the electric plotter model. In the same manner, hydraulic divides can be fairly accurately located. Even such unknowns as unmeasurable groundwater discharges can usually be determined. Finally, the forecast of conditions which may occur in the future can be made because of the possibility of incorporating a time scale into the hydraulic model tests.

## BIBLIOGRAPHY

1. Brown, R. H. and Skibitzke, H. E.: "Theoretical Groundwater Movement Based on Electrical Analogs," Analysis of Basic Data Concerning Groundwater in the Yuma Area, Arizona, USGS Report, 1956.

2. Day, Paul R.: "Dispersion of a Moving Salt Water Boundary," Transactions of the American Geophysical Union, Vol. 37, No. 5, October 1956.

3. Drescher, W. J.: "Some Effects of Precipitation on Ground Water in Wisconsin," Wisconsin Geological Survey, University of Wisconsin, Information Circular No. 1, 1955.

4. Drescher, W. J.: "Ground Water in Wisconsin," Wisconsin Geological Survey, University of Wisconsin, Information Circular No. 3, 1956.

5. Ferris, J. G. and Sayre, A. N.: "The Quantitative Approach to Ground-Water Investigations," Economic Geology, Fiftieth Anniversary Volume, 1955.

6. Hubbert, M. K.: "The Theory of Ground Water Motion," The Journal of Geology, Vol. XLVIII, No. 8, November-December 1940.

7. Krul, W. F. J. M., and Liefrinck, F. A.: Recent Groundwater Investigations in The Netherlands, Elsevier Publishing Co., Inc., New York, 1946.

8. Parker, G. G.: "Water," The Yearbook of Agriculture, 1955, U. S. Department of Agriculture, Washington, D. C., pp 615-620.

9. Slichter, C. S.: Field Measurements of the Rate of Movement of Underground Waters, U. S. Department of the Interior, Washington, D. C., 1904, pp 29-49.

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## PROCEEDINGS PAPERS

The technical papers published in the past year are identified by number below. Technical-division sponsorship is indicated by an abbreviation at the end of each Paper Number, the symbols referring to: Air Transport (AT), City Planning (CP), Construction (CO), Engineering Mechanics (EM), Highway (HW), Hydraulics (HY), Irrigation and Drainage (IR), Pipeline (PL), Power (PO), Sanitary Engineering (SA), Soil Mechanics and Foundations (SM), Structural (ST), Surveying and Mapping (SU), and Waterways and Harbors (WW), divisions. Papers sponsored by the Department of Conditions of Practice are identified by the symbols (PP). For titles and order coupons, refer to the appropriate issue of "Civil Engineering." Beginning with Volume 82 (January 1956) papers were published in Journals of the various Technical Divisions. To locate papers in the Journals, the symbols after the paper number are followed by a numeral designating the issue of a particular Journal in which the paper appeared. For example, Paper 1859 is identified as 1859 (HY 7) which indicates that the paper is contained in the seventh issue of the Journal of the Hydraulics Division during 1958.

### VOLUME 83 (1957)

DECEMBER: 1449(HY6), 1450(HY6), 1451(HY6), 1452(HY6), 1453(HY6), 1454(HY6), 1455(HY6), 1456(HY6)[c], 1457(PO6), 1458(PO6), 1459(PO6), 1460(PO6)[c], 1461(SA6), 1462(SA6), 1463(SA6), 1464(SA6), 1465(SA6), 1466(SA6)[c], 1467(AT2), 1468(AT2), 1469(AT2), 1470(AT2), 1471(AT2), 1472(AT2), 1473(AT2), 1474(AT2), 1475(AT2), 1476(AT2), 1477(AT2), 1478(AT2), 1479(AT2), 1480(AT2), 1481(AT2), 1482(AT2), 1483(AT2), 1484(AT2), 1485(AT2)[c], 1486(BD2), 1487(BD2), 1488(PO6), 1489(PO6), 1490(BD2), 1491(BD2), 1492(HY6), 1493(BD2).

### VOLUME 84 (1958)

JANUARY: 1494(EM1), 1495(EM1), 1496(EM1), 1497(IR1), 1498(IR1), 1499(IR1), 1500(IR1), 1501(IR1), 1502 (IR1), 1503(IR1), 1504(IR1), 1505(IR1), 1506(IR1), 1507(IR1), 1508(ST1), 1509(ST1), 1510(ST1), 1511(ST1), 1512(ST1), 1513(WW1), 1514(WW1), 1515(WW1), 1516(WW1), 1517(WW1), 1518(WW1), 1519(ST1), 1520 (EM1)[c], 1521(IR1)[c], 1522(ST1)[c], 1523(WW1)[c], 1524(HW1), 1525(HW1), 1526(HW1)[c], 1527(HW1).

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JUNE: 1658(AT1), 1659(AT1), 1660(HY3), 1661(HY3), 1662(HY3), 1663(HY3), 1664(HY3), 1665(SA3), 1666 (PL2), 1667(PL2), 1668(PL2), 1669(AT1), 1670(PO3), 1671(PO3), 1672(PO3), 1673(PL2), 1674(PL2), 1675 (PO3), 1676(PO3), 1677(SA3), 1678(SA3), 1679(SA3), 1680(SA3), 1681(SA3), 1682(SA3), 1683(PO3), 1684 (HY3), 1685(SA3), 1686(SA3), 1687(PO3), 1688(SA3)[c], 1689(PO3)[c], 1690(HY3)[c], 1691(PL2)[c].

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AUGUST: 1725(HY4), 1726(HY4), 1727(SM3), 1728(SM3), 1729(SM3), 1730(SM3), 1731(SM3), 1732(SM3), 1733 (PO4), 1734(PO4), 1735(PO4), 1736(PO4), 1737(PO4), 1738(PO4), 1739(PO4), 1740(PO4), 1741(PO4), 1742 (PO4), 1743(PO4), 1744(PO4), 1745(PO4), 1746(PO4), 1747(PO4), 1748(PO4), 1749(PO4).

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DECEMBER: 1859(HY7), 1860(IR4), 1861(IR4), 1862(IR4), 1863(SM5), 1864(SM5), 1865(ST8), 1866(ST8), 1867 (ST8), 1868(PP1), 1869(PP1), 1870(PP1), 1871(PP1), 1872(PP1), 1873(WW5), 1874(WW5), 1875(WW5), 1876 (WW5), 1877(CP2), 1878(ST8), 1879(ST8), 1880(HY7)[c], 1881(SM5)[c], 1882(ST8)[c], 1883(PP1)[c], 1884(WW5)[c], 1885(CP1)[c], 1886(PO6), 1887(PO6), 1888(PO6), 1889(PO6), 1890(HY7), 1891(PP1).

[c] Discussion of several papers, grouped by divisions.

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